Programmable Logic Application Notes

by Richard Katz
Microelectronics and Signal Processing Branch
Goddard Space Flight Center
301-286-9705
rich.katz@gsfc.nasa.gov
http://rk.gsfc.nasa.gov

This column will be provided each quarter as a source for reliability, radiation results, NASA capabilities, and other information on programmable logic devices and related applications. This quarter's column will include some announcements and some recent radiation test results and evaluations of interest. Specifically, the following topics will be covered: the Military and Aerospace Applications of Programmable Devices and Technologies Conference to be held at GSFC in September, 1998, proton test results, heavy ion test results, and some total dose results.

MAPLD

Registration is now open for the Military and Aerospace Applications of Programmable Devices and Technologies Conference, to be held at NASA's Goddard Space Flight Center September 15-16, 1998. Late news poster papers are also being accepted. The program will consist of 4 invited talks, 4 technical sessions, a poster session, and an industrial exhibit. For registration and program information, including abstracts, please see http://rk.gsfc.nasa.gov.

NSREC '98

The 35th Annual Nuclear and Space Radiation Effects Conference was held in Newport Beach, California, July 20-24. Several papers were presented covering programmables and ASICs including: *Current Radiation Issues for Programmable Elements and Devices*, R. Katz, et. al., which gives an overview of state-of-the-art technology and their radiation characteristics, *Erasure of Floating Gates in the Natural Radiation Environments of Space*, P. McNulty, et. al., which discussed the floating gate technology, *Single Event Effect and Proton Damage Results for Candidate Spacecraft Electronics*, M. O'Bryan, et. al., which gives a broad overview of recent technologies, *Total Dose and Single Event Effects Testing of UTMC Commercial RadHard Gate Arrays*, D. Kerwin, et. al., showing radiation-hard performance, *High Total Dose Response of the UTMC Gate Array Fabricated at Lockheed-Martin Federal Systems*, J. Benedetto, et. al., showing the capability of the ASIC on the radiation-hardened line, *Total Ionizing Dose Effects on Flash Memories*, D. Nguyen, et. al., showing the effect of internal cell structures and charge pumps on radiation performance, *Anatomy of an In-flight Anomaly: Investigation of Proton-Induced SEE Test Results for Stacked IBM DRAMs*, K. LaBel, et. al., discusses test techniques for devices with small cross-sections, including the A1280A, etc., and *Neutron Single Event Upsets in SRAM-based FPGAs*, discusses the performance of an SRAM-based FPGA with neutrons.

MAPLUG

A military/aerospace programmable logic users group is being formed. The goal of the organization is, similar to other disciplines, promote sharing of ideas, techniques, information, product announcements, alerts, and experiences between users of the technology, parts and reliability engineers, and vendors. Individuals and vendors may join by emailing: maplug@gsfc.nasa.gov. There will be no fee and no advertising. Membership lists will by default not be distributed as we wish to remain spam-free.

Proton Test Results from IUCF

A variety of FPGAs and a quick-turn ASIC was tested at the Indiana University Cyclotron Facility in June, 1998. All tests were run with ~ 193 MeV protons; the fluence varied according to the part type and test being performed. Devices tested were the RH1020, QL3025, A1280A/MEC, A54SX16 prototype (CSM), RT54SX16 prototype (MEC), and the QYH530 (Yamaha, two lots). The internal code name 'CKJ911' was used for the A54SX16 prototype in the test report.

Below are reports on each of the tests. These are available on-line at http://rk.gsfc.nasa.gov. Key results included good SEU performance of the 0.35 μm/3.3V devices from Actel and Quicklogic. Small cross-sections were measured for the RH1020 and the A1280A devices. No upsets were detected in the QYH530, operated at V_{CC} = 3.3VDC.

Total dose responses of the devices involved in this test was also measured, with I_{CC} vs. total dose curves given for many of the devices; tables are provided for some. There was reasonable agreement between the radiation response with protons and the Cobalt-60 radiation tests. No latchups, clock upsets, or configuration upsets were detected from SEU affects.

Summary of Proton Test on the Actel A1280A at

Indiana University

June, 1998

Prepared by: R. Katz, K. LaBel NASA/GSFC

Date: June 23, 1998

Test Facility

The Actel A1280A FPGA was tested at the Indiana University Cyclotron Facility (IUCF). The proton energy was 193 MeV and the flux was set at approximately 2 x 10^8 p/cm^2/sec. The total fluence for each device was determined by the total dose response of the device and it's affect on the current draw; details for each device including bias are given in the tables below. The device was irradiated normal to the beam.

Device Under Test

The A1280A devices were in a CPGA176 package and were active during irradiation. All die were from the Matsushita (MEC) foundry with a 1.0 μm feature size. Upsets and currents were monitored in real-time with the device being clocked at 1 MHz. The stimulation pattern was a 500 kHz square wave. The test pattern used, the TMRA2.C, contains 522 S-Module flip-flops and 40 C-Module flip-flops.

Sample devices were taken from several lots used previously in radiation tests along with a few 'spare devices' to increase sample size. A total of 19 devices were used in this study. The intent of the study was to investigate the proton response of the hard-wired S-Module flip-flops with a large sample size. Previous testing did not detect proton upset within the operating voltage range but used a low fluence.

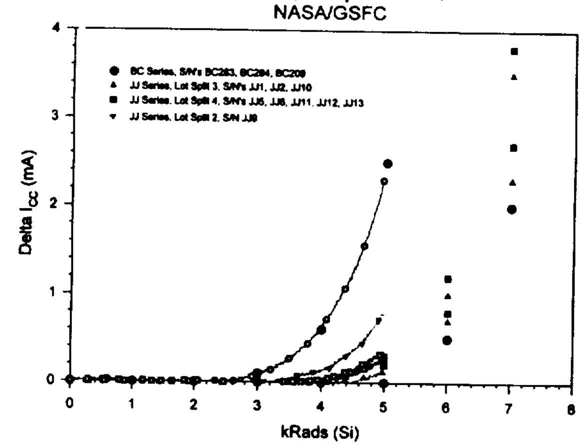
Test Results

Nineteen devices were irradiated, with 12 devices at a worst-case bias of 4.5V and the remaining 7 devices at a nominal bias of 5.0V. An estimate of the cross-sections, by lot and bias, are given in Table 1 and Table 2, above. Previous tests of the A1280 (1.2 μm) and the A1280A (1.0 μm) did not detect proton upset. The large sample size for this study, with upsets detected in each device, shows that this device is sensitive to protons for S-Modules. No upsets were detected in the C-module flip-flops. However, there was a small number of flip-flops in this pattern so a different pattern should be used for measuring the C-module flip-flops' sensitivity to protons. Note that the C-module flip-flops in the RH1020, tested in June 1998, have a small, but non-zero cross-section for 193 MeV protons.

There was no clock upset detected in any of the devices.

The device's total dose performance falls into the radiation-soft range, typical for devices of this class. The data within a lot was relatively consistent.

A1280A Proton Test
V_{CC} = 4.5 VDC
Indiana University, June, 1998
193 MeV, 2E8 p/cm^2/Sec
NASA/GSFC



A1280A Proton Test
V_{CC} = 5.0 VDC
Indiana University, June, 1998
193 MeV, 2E8 p/cm^2/Sec
NASA/GSFC

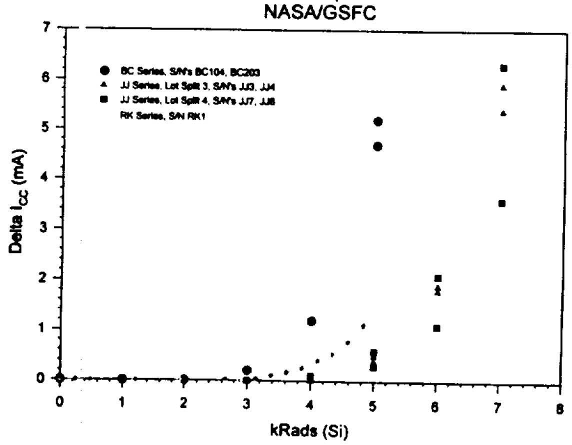


Table 1. Summary for V_{CC} = 4.5VDC.

S/N	Lot	Total Dose kRads (Si)	Upsets	Fluence (p/cm^2)	Estimated Cross-Section (cm^2/flip-flop) by Lot
BC284	9424	5	6	80×10^9	96×10^{-15}
BC283	9424	5	2	80×10^9	
BC209	9424	5	4	80×10^9	
JJ9	9614 Lot Split 2	5	5	80×10^9	120×10^{-15}
JJ1	9614 Lot Split 3	7	13	112×10^9	139×10^{-15}
JJ2	9614 Lot Split 3	7	7	112×10^9	
JJ10	9614 Lot Split 3	5	2	80×10^9	
JJ5	9614 Lot Split 4	7	9	112×10^9	165×10^{-15}
JJ6	9614 Lot Split 4	7	14	112×10^9	
JJ11	9614 Lot Split 4	5	6	80×10^9	
JJ12	9614 Lot Split 4	5	4	80×10^9	

Table 2. Summary for V_{CC} = 5.0VDC.

S/N	Lot	Total Dose kRads (Si)	Upsets	Fluence (p/cm^2)	Estimated Cross-Section (cm^2/flip-flop) by Lot
JJ3	9614 Lot Split 3	7	7	112×10^9	137×10^{-15}
JJ4	9614 Lot Split 3	7	9	112×10^9	
BC203	9424	5	5	80×10^9	83.8×10^{-15}
BC104	9424	5	2	80×10^9	
JJ7	9614 Lot Split 4	7	8	112×10^9	154×10^{-15}
JJ8	9614 Lot Split 4	7	10	112×10^9	
RK1	9415	5	4	80×10^9	95.8×10^{-15}

Summary of Proton Test on the Actel RH1020 at

Indiana University

June, 1998

Revision A.
Prepared by: R. Katz, NASA/GSFC
Date: June 18, 1998

Test Facility

The Actel RH1020 was tested at the Indiana University Cyclotron Facility (IUCF). The proton energy was 193 MeV and the flux was set at approximately 1×10^9 p/cm^2/sec. The total fluence for each device was 1.6×10^{12} p/cm^2 corresponding to a total dose of 100 kRads (Si); details for each device including bias are given in the tables below. The device was irradiated normal to the beam.

Device Under Test

The devices were in a CQFP84 package and were active during irradiation. Upsets and currents were monitored in real-time with the device being clocked at 1 MHz. The stimulation pattern was a 500 kHz square wave. Since the devices are quite hard to total dose effects, the test equipment was run in an SEU time-tagging mode to aid in the detection and instrumentation of clock upsets. The test pattern used, TMRA1BRB, contains 136 flip-flops with 102 in a TMR configuration and 34 in a shift register. The Act 1 architecture only has routed flip-flops; there are no hard-wired or I/O module flip-flops.

Sample devices were taken from two lots, a "pre-production" lot and a production lot. In this case, the difference between the devices were an improved clock buffer for 'clock upset' (production lot) and the thickness of the antifuses, with the production devices having a 90Å thick antifuse and the pre-production devices having a 96Å thick antifuse.

Test Results

The table included below summarizes the device, bias conditions, and irradiation.

Five devices were irradiated with a 5V bias and three with a 4.5 bias with a total of 3 upsets for all of the runs. The cross-sections can be estimated as 1.8×10^{-15} cm^2/flip-flop at V_{CC} = 5V and 1.5×10^{-15} cm^2/flip-flop at V_{CC} = 4.5VDC. Obviously, with the small error counts, the statistics are poor, and it would be expected that the device would have a larger cross-section at the lower bias level.

There was no evidence of any clock upset in either the pre-production devices or the hardened production lot.

The device's total dose performance was excellent, with changes of currents not exceeding more than a few hundred microamps. This also shows, as expected, no antifuse damage. Previous testing has shown that at LET = 37 MeV-cm^2/mg, a bias of 6.1 volts was necessary to rupture a production device (two samples tested). Note also that these devices had already been previously irradiated during heavy ion tests.

S/N	Lot	Bias (Volts)	Total Dose kRads (Si)	Upsets	Fluence (p/cm$_2$)
RH3	Production	5.0	100	0	1.6×10^{12}
RH4	Production	5.0	100	0	1.6×10^{12}
RH6	Production	5.0	100	2	1.6×10^{12}
RH1095	Pre-Production	4.5	100	0	1.6×10^{12}
RH1098	Pre-Production	4.5	100	1	1.6×10^{12}
RH1099	Pre-Production	5.0	100	0	1.6×10^{12}
RH1101	Pre-Production	5.0	100	0	1.6×10^{12}
RH3769	Pre-Production	4.5	100	0	1.6×10^{12}

Summary of Proton Test on the Actel CKJ911

Prototype at Indiana University

June, 1998

Prepared by: R. Katz, NASA/GSFC

Date: June 18, 1998

Test Facility

The Actel CKJ911 prototype FPGA was tested at the Indiana University Cyclotron Facility (IUCF). The proton energy was 193 MeV and the flux was set at approximately 1 x 10^9 p/cm^2/sec. The total fluence for each device was determined by the total dose response of the device and it's affect on the current draw; details for each device including bias are given in the chart below. The device was irradiated normal to the beam.

Device Under Test

The devices were in a PQFP208 package and were active during irradiation. Upsets and currents were monitored in real-time with the device being clocked at 1 MHz. The stimulation pattern was a 500 kHz square wave. The test pattern used contains 400 flip-flops. The CKJ911 architecture only has hard-wired flip-flops with the available software; there are no I/O module flip-flops.

Sample devices were taken from a prototype lot, with I_{DDSB} currents higher than would be expected from a full-scale production lot. The "p-fuse" was not programmed on these devices and the TCK pin (an input to the IEEE 1149.1 JTAG TAP controller) was not active.

Test Results

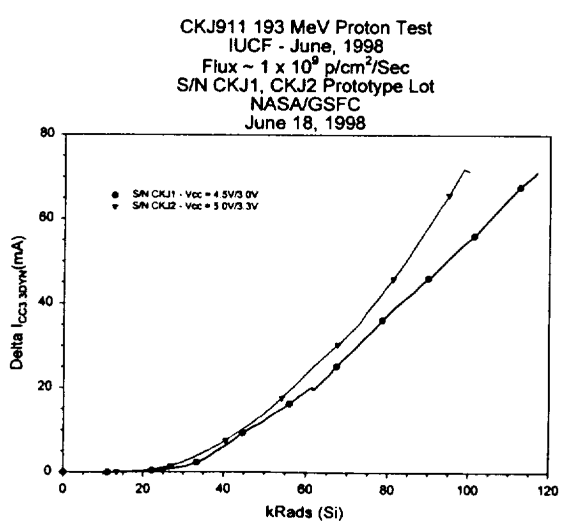
The following table summarizes the device, bias conditions, and irradiations.

S/N	Lot	Bias (Volts)	Total Dose kRads (Si)	Upsets	Fluence (p/cm$_2$)
CKJ1	Prototype	4.5/3.0	116.9	2	1.9 x 10^{12}
CKJ2	Prototype	5.0/3.3	100.1	0	1.6 x 10^{12}

Two devices were irradiated, one with biases of 4.5V and 3.0V and the other with biases of 5.0V and 3.3V. An estimate of an upper bound for the cross-sections can be computed as 2.6 x 10^{-15} cm^2/flip-flop at the worst-case voltage and, assuming a single upset, as 1.6 x 10^{-15} cm^2/flip-flop at nominal supply voltages.

There was no clock upset detected in any of the devices and no upsets were detected in the JTAG TAP controller.

The device's total dose performance was good, despite the high initial device bias currents. The dose rate was high at 252 kRads (Si) / hour for S/N CKJ1 and 316 kRads (Si) / hour for S/N CKJ2. Details are shown in the strip charts below for the 3.3V supply currents. Only moderate (< 250 μA) changes in the 5V bias currents were observed.



Summary of Proton Test on the Actel

RT54SX16 Prototype at Indiana University

June, 1998

Prepared by: R. Katz, NASA/GSFC

Date: June 18, 1998

Test Facility

The Actel RT54SX16 prototype FPGA was tested at the Indiana University Cyclotron Facility (IUCF). The proton energy was 193 MeV and the flux was set at approximately 1 x 10^9 p/cm^2/sec. The total fluence for each device was determined by the total dose response of the device and it's affect on the current draw; details for each device including bias are given in the chart below. The device was irradiated normal to the beam.

Device Under Test

The devices were in a PQFP208 package and were active during irradiation. Upsets and currents were monitored in real-time with the device being clocked at 1 MHz. The stimulation pattern was a 500 kHz square wave. The test pattern used contains 400 flip-flops. The RT54SX16 architecture only has hard-wired flip-flops with the available software; there are no I/O module flip-flops.

Sample devices were taken from a prototype lot, and $I_{DDSTDBY}$ currents were normal, just a few hundred microamps. The "p-fuse" was programmed on these devices and the TCK pin (an input to the IEEE 1149.1 JTAG TAP controller) was not active for runs with S/N MKJ1 and MKJ2; it was active at 6 kHz for MKJ3. The date code was 9733 with the chip also marked as PO6GNC WFR #7,8.

Test Results

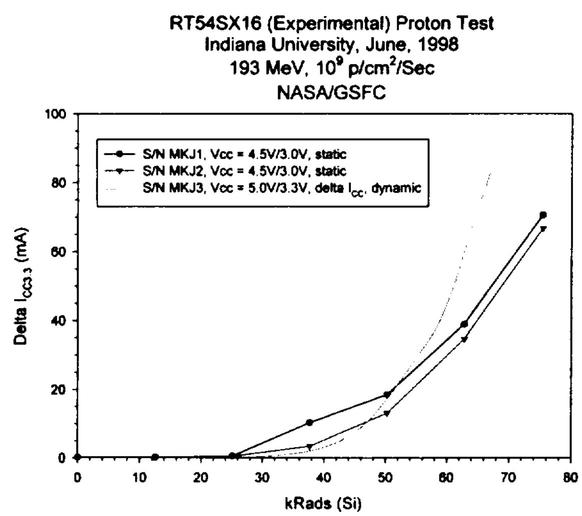
The following table summarizes the device, bias conditions, and irradiations.

S/N	Lot	TCK	Bias (Volts)	Total Dose kRads (Si)	Upsets	Fluence (p/cm^2)
MKJ1	Prototype D/C 9733	Off	4.5/3.0	75.4	2	1.2 x 10^{12}
MKJ2	Prototype D/C 9733	Off	4.5/3.0	75.4	4	1.2 x 10^{12}
MKJ3	Prototype D/C 9733	6 kHz	5.0/3.3	103.1	2	1.6 x 10^{12}

Three devices were irradiated, two with worst-case biases of 4.5V and 3.0V and the other with a nominal biases of 5.0V and 3.3V. An estimate of the cross-sections can be computed as 6.3 x 10^{-15} cm^2/flip-flop at the worst-case voltage and as 3.1 x 10^{-15} cm^2/flip-flop at nominal supply voltages. Obviously, with the low error counts, more devices would be needed to get an accurate cross-section.

There was no clock upset detected in any of the devices and no upsets were detected in the JTAG TAP controller.

The device's total dose performance was good, falling into the rad-tolerant range. The curves for S/N MKJ1 and S/N MKJ2 are made by plotting static currents at the end of each proton run, with the symbols representing each step. The curve for S/N MKJ3 is the delta current recorded during the run. The dose rate was high at about 250 kRads (Si) / hour. Only moderate (< 1.5 mA) changes in the 5V bias currents were observed for S/N MKJ1 and S/N MKJ2. For S/N MKJ3, which had the higher total dose, the 5V bias current increased to 1.1 mA after 67 kRads (Si) and to 8.1 mA after 103 kRads (Si). Note that further experiments on this part type has shown lot splits with > 100 kRads (Si) total dose capability.



Summary of Proton Test on the Chip Express QYH530 at Indiana University

June, 1998

Prepared by: R. Katz, NASA/GSFC

Date: June 17, 1998

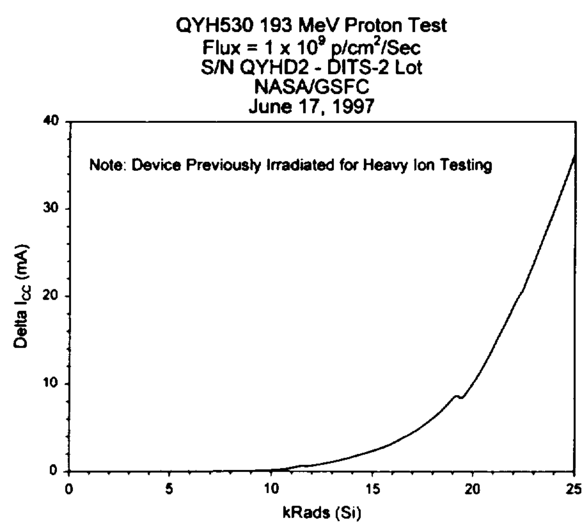
Test Facility

The Chip Express QYH530 was tested at the Indiana University Cyclotron Facility (IUCF). The proton energy was 193 MeV and the flux was set at approximately 1 x 10^9 p/cm^2/sec. The total fluence for each device was determined by the total dose response of the device and it's affect on the current draw; details for each device including bias are given in the tables below. The device was irradiated normal to the beam.

Device Under Test

The devices were in a PGA180 package and were active during irradiation. Upsets and currents were monitored in real-time with the device being clocked at 1 MHz. The stimulation pattern was a 500 kHz square wave. The test pattern used contains 1200 flip-flops. The QYH500 architecture only has routed flip-flops; there are no hard-wired or I/O module flip-flops.

Sample devices were taken from two lots, a "DITS-2" flight lot and a production lot used for shielding experiments; no radiation shields were used on any of the devices in this test. All devices were processed with Chip Express' One-Mask technology with no laser programmed devices tested during these runs. These devices had already been subjected to heavy ion tests at Brookhaven National Laboratory.



Test Results

The following table summarizes the device, bias conditions, and irradiations.

S/N	Lot	Bias (Volts)	Total Dose kRads (Si)	Upsets	Fluence (p/cm^2)
QYHD1	DITS-2	4.5	18.9	0	0.3×10^{12}
QYHD2	DITS-2	3.3	25.1	0	0.4×10^{12}
QYHD3	DITS-2	3.3	25.1	0	0.4×10^{12}
QYH55	LOT OF 70	3.3	25.1	0	0.4×10^{12}
QYH56	LOT OF 70	3.3	25.1	0	0.4×10^{12}

Five devices were irradiated, one with a 4.5V bias and four with a 3.3 bias with no upsets for all of the runs. An estimate of an upper bound for the cross-sections can be computed, assuming a single upset, as 0.5×10^{-15} cm^2/flip-flop. There was no clock upset detected in any of the devices.

The device's total dose performance was good, even though the devices had been previously irradiated. Nevertheless, the following table and figure shows radiation-tolerant performance. The dose rate was high at 216 kRads (Si) / hour.

Table 1. Static current after each run in mA.

Note: Devices previously irradiated with heavy ions.

	6.3 kRads (Si)	12.6 kRads (Si)	18.8 kRads (Si)	25.1 kRads (Si)
QYHD1	0	1.7	31.6	
QYHD2	0	0.6	8.5	35.9
QYHD3	0	0.0	7.3	32.9
QYH55	0	0.2	5.1	25.5
QYH56	0	0.0	3.3	23.3

Summary of Proton Test on the Quick Logic

QL3025 at Indiana University

June, 1998

Prepared by: R. Katz,
NASA/GSFC

Date: June 16, 1998

Test Facility

A pAsic3 QL3025 was tested at the Indiana University Cyclotron Facility (IUCF). The proton energy was ~ 193 MeV and the flux was set at approximately 1×10^9 p/cm^2/sec. The total fluence for the run was 5.12×10^{11} p/cm^2 corresponding to a total dose of 32.1 kRads (Si). The device was irradiated normal to the beam.

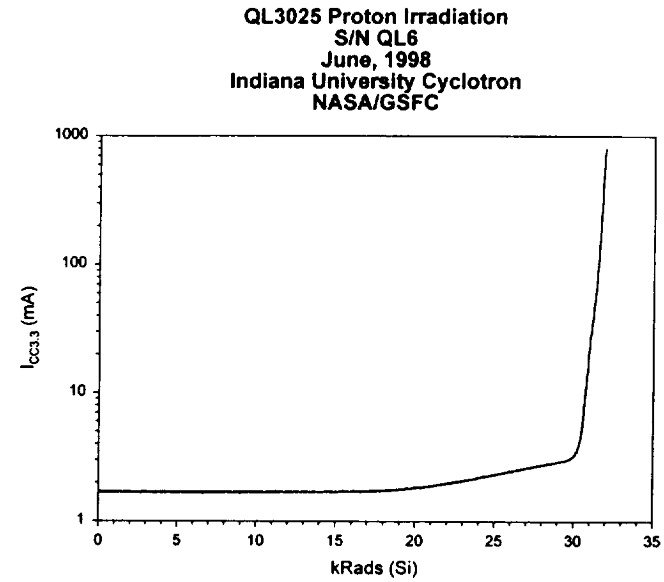
Device Under Test

The device was in a PQFP208 package and was active during irradiation. Upsets and currents were monitored in real-time with the device active at 1 MHz. The stimulation pattern was a 500 kHz square wave. Both internal hard-wired flip-flops and I/O module flip-flops were tested. This pattern contains 500 internal flip-flops with 300 in a TMR configuration and 200 in a shift register. 50 I/O module flip-flops were tested.

Test Results

No upsets were detected for this one sample, consistent with our quick-look heavy ion data, taken at an LET of 18.8 MeV-cm^2/mg. The total fluence for the heavy ion data was limited and complicated by the device's latchup characteristics. No evidence of latchup or any unusual current disturbances were observed.

The device showed a moderate increase in current at approximately 20 kRads (Si) and a current runaway at approximately 31 kRads (Si). This is thought to be a consequence of a charge pump failure. The total dose data, shown in the chart below, is comparable to our Cobalt-60 data where the device exhibited runaway at approximately 37 kRads (Si), while dosed at the relatively low rate of 0.5 kRads (Si)/hour in a static configuration. Dose rate during the proton irradiation was at the much higher rate of ~ 247 kRads (Si)/hour.



Functional Failure of EEPROMs in the Heavy Ion Environment

It has been demonstrated that devices, including EEPROMs, may lose functionality when upset by a single heavy ion. The Atmel AT28C010 is one example. Additionally, excess current was observed in the device. No permanent damage was detected. For the AT28C010, three types of SEUs were identified. one type was an upset in the output register, causing a read operation to fail. Additionally, there were two types of upsets where the device lost functionality over multiple cycles and entering a non-operating state.

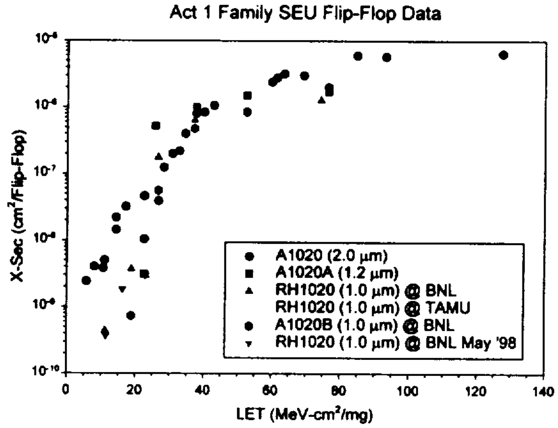
This phenomena was covered in a good overview in "Single Event Functional Interrupt (SEFI) in Microcircuits," published in RADECS 97, Proceedings of the Fourth European Conference on Radiation and its Effects on Components and Systems. The authors are R. Koga, S. Penzin (Crain), K. Crawford, and W. Crain from the Aerospace Corporation.

Recently, a similar effect was demonstrated and analyzed in FPGAs utilizing IEEE 1149.1 JTAG circuitry, in an implementation without the optional TRST- pin. An application note on use of JTAG is in preparation and will be published shortly.

Act 1 SEU Summary

The Act 1 architecture has been fabricated in a number of technologies, many of which are utilized in space flight hardware. These consist primarily of the MEC foundry 2.0, 1.2, and 1.0 μm devices as well as the RH1020 built at Lockheed-Martin. The following chart summarizes the SEU performance of these devices. Some other variants are being flown, such as the TI A1020B, but this is relatively infrequent and the data is not included here.

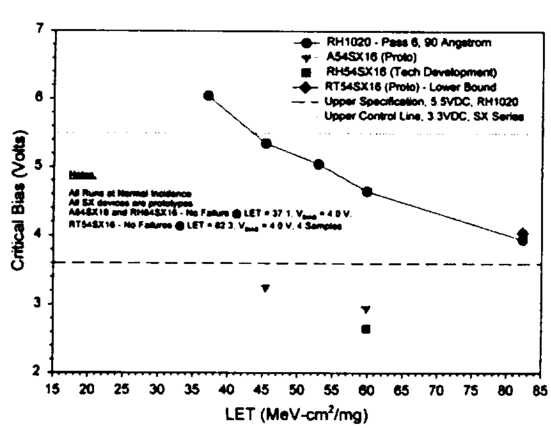
Act 1 Family SEU Flip-Flop Data



Antifuse Hardness

The following chart gives an update on antifuse hardness testing. Shown here is data on the RH1020 devices as well as prototypes from the SX series of FPGAs. Please note that these are prototypes used for technology assessment and development. Characteristics of production devices will differ and the user should be sure to obtain up-to-date data.

Antifuse Rupture Data
RK (NASA), JJ (Actel), JM (Actel)
BNL 2/98, 5/98, 7/98

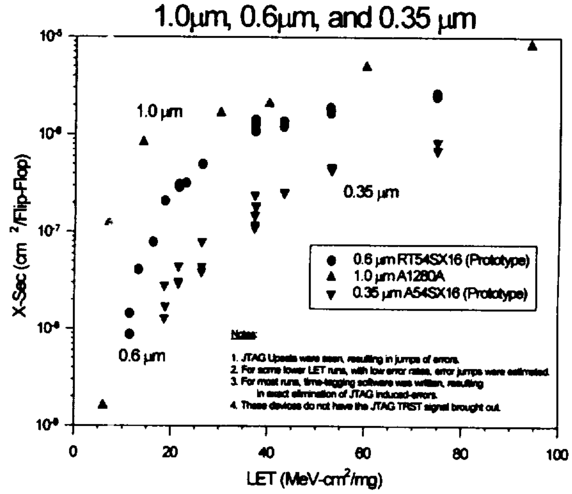


None of the antifuse 'recipes' showed any problems at an LET of 37 MeV-cm²/mg with the ions normal to the device, which is worst-case for this effect. Note that the usual cosine law for SEU and SEL do not apply here. Of particular note is antifuse recipe 'M', which was hard (four sample devices) at an LET of 82.3 MeV-cm²/mg with V_{DD} = 4.0 VDC; maximum rated voltage for this class of device is 3.6 VDC.

SEU Comparison of 1.0, 0.6, and 0.35 μm *Hard-wired* Flip-Flops

The following chart shows the SEU response of *hard-wired* flip-flops from an A1280A (5V/1.0 μm) and prototype RT54SX16 (3.3V/0.6 μm) and A54SX16 (3.3V/0.35 μm) devices. The hard-wired flip-flops are dedicated on the chip and are not formed by feedback connections in the routing channels. These are called 'S-Module flip-flops' in the A1280A and 'R-Cell' in the SX architecture.

SEU Response of Hard-wired Flip-Flops
1.0μm, 0.6μm, and 0.35 μm

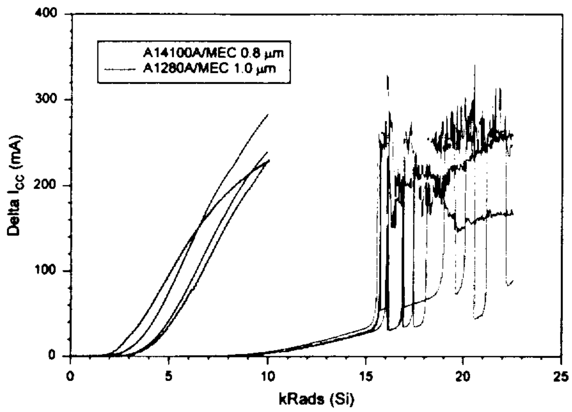


As can be seen, the smaller feature-sized parts, operating with the lower bias voltage, had improved single event upset (SEU) performance over its older, higher voltage predecessors. As can be seen from the proton data, and limited heavy ion data, the QL3025 3.3V/0.35 μm device also performed well. Modern FPGAs will continue to scale and we expect to have test 0.25 μm feature size in the near future.

Recent Act 2 and Act 3 Total Dose Results

Below is a chart showing total ionizing dose (TID) test results for flight lots of A1280A/MEC (left) and A14100A/MEC (right). Static I_{CC} is plotted against accumulated dose.

Recent 0.8 and 1.0 μm TID Results



As can be seen, these lots of devices are performing worse that 'typical' lots of these device types. While our database is not large enough to declare a trend, the decrease in TID performance is being watched, closely. A second batch of A14100A's are being qualified to 11 ± 10% kRads (Si) and are currently in high-temperature annealing.

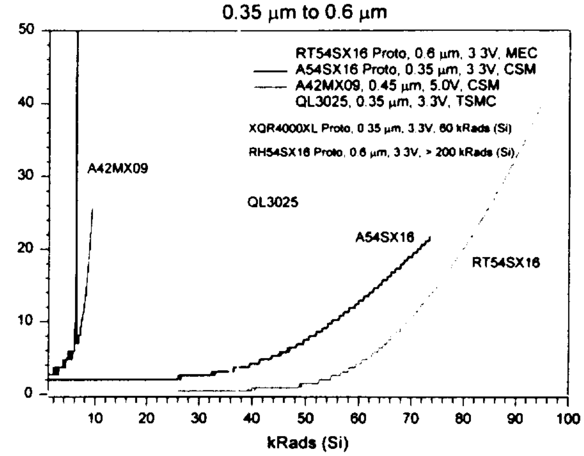
Additional data sets will be obtained in the near term, with lots of A1425A/MEC, A1460A/MEC, and A1280A/MEC being queued for test.

Recent Sub-micron Total Dose Results

The graph below summarizes the performance of sub-micron devices recently testing. Data on the prototype XQR4062XL, using a modified process, was supplied by Xilinx Corporation. Note that heavy ion test data for this prototype devices showed no latchup at an LET = 100 MeV-cm^2/mg, at a temperature of 100°C.

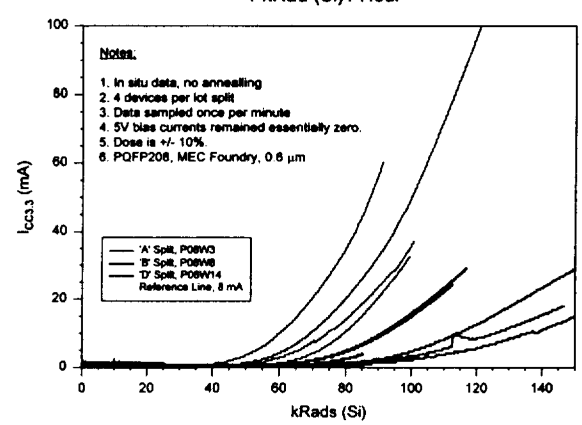
The 5.0VDC/0.45 μm A42MX09 sample did poorly, with less than 10 kRads (Si) performance. All of the 3.3V/submicron devices did well, showing radiation-tolerant performance. All devices, except for the XQR4062XL, used unmodified processes. The RH54SX16 prototype, previously published, showed no degradation to 200 kRads (Si), with the results limited by available test time.

Submicron FPGA TID Tolerance
0.35 μm to 0.6 μm



The following chart shows the results from modifications made to prototype RT54SX16's, with the results for three lot splits shown. The reference line is arbitrary and is used as a very conservative estimate of performance and a means for making comparisons between the lot splits. Even without annealing, performance levels exceeding 100 kRads (Si) were achieved on a commercial fabrication line.

RT54SX16 Prototype
Lot Split TID Test
NASA/GSFC - Actel
July 3, 1998
1 kRad (Si) / Hour



Miscellaneous

A number of items of interest are on the www site. This includes data, such as heavy ion and total dose tests on Chip Express devices, presentations from the SEE Symposium (April, 1998 in LA), and more research papers on topics such as antifuse reliability and efficiently supporting fault-tolerance in FPGAs. TID papers on EEPROMs are also being posted.

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